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Architectural and Engineering Factors in Solar Systems Design

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U.S. Department of Energy

National Solar Heating and Cooling Demonstration Program

National Solar Data Program

NOTICE

A key part of the national solar demonstration program is the acquisition and dissemination of data generated by the demonstration projects. The Ehrenkrantz Group, Architects and Planners, as a subcontractor to PRC Energy Analysis Company under contract to the Department of Energy, has been involved in this process for more than a year. The following paper, based on the review and analysis of over 70 projects, will focus on some of the most common design and construction problems. Structural details and specifications and some trade-offs that can make for a more cost-effective project will be addressed rather than mechanical considerations, such as collector selection.

ECONOMIC CONSIDERATIONS

THE SOLAR DESIGNER IS WORKING WITH RELATIVELY LOW LEVELS OF THERMAL ENERGY.

THIS LIMITS THE AMOUNT OF MONEY THAT CAN BE PRUDENTLY EXPENDED ON THE COLLECTION AND TRANSPORT OF SOLAR ENERGY.

The whole solar installation must be value-engineered to arrive at the lowest first cost consistent with quality of materials and workmanship required. The desire to extract every theoretical Btu from a system often leads to the installation of extra devices that will not be cost-effective and will only increase the payback period of the project.

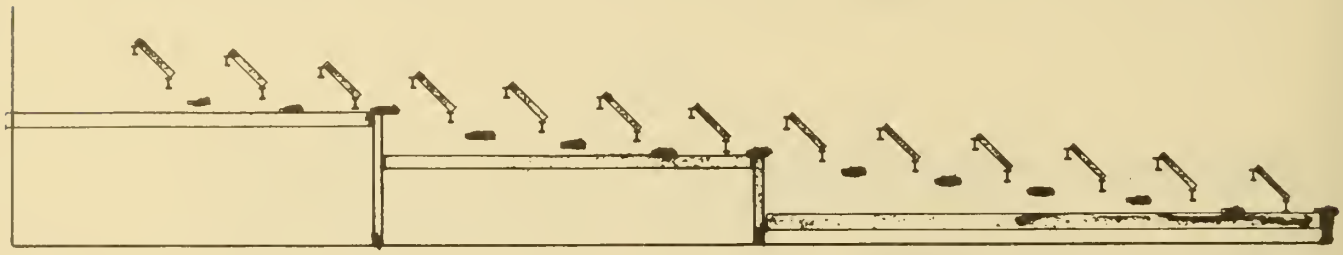
CONSTRUCTION CONSIDERATIONS

SOLAR COLLECTION SYSTEMS TYPICALLY REQUIRE CONSIDERABLY MORE EXPOSED EXTERIOR CONSTRUCTION THAN THE BUILDING TRADES ARE ACCUSTOMED TO

THEREFORE, THE DESIGNER MUST ISOLATE AND SOLVE CONSTRUCTION PROBLEMS AND NOT LEAVE DECISIONS TO THE CONTRACTOR.

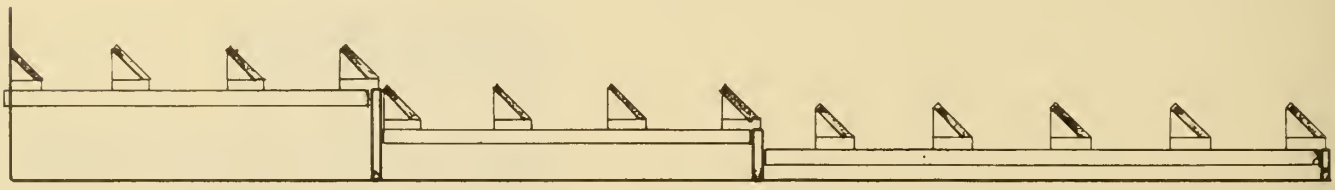
If we look out over a typical residential or commercial building roofscape we see a minimal amount of exposed construction, especially piping. As a result, the building trades cannot be expected to bring prior experience to bear in solving typical problems that accompany solar projects with their large amount of exposed exterior construction.

Layout and Access vs. Cost--Some considerations that have an impact on costs involve the collectors and structural layouts and the degree of accessibility provided to the collectors and piping for servicing. The designer feels that immediate access to all parts of the array is mandatory, especially in the case of evacuated tube designs. One of the more handsome designs we have seen provides accessibility to each row of collectors.

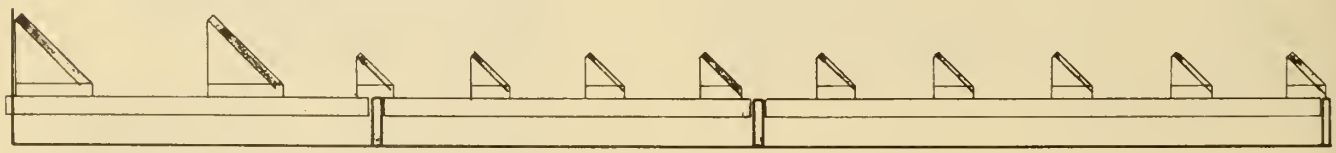


Each row of collectors is slightly higher than the one in front of it, with accessibility to piping and collectors in the form of a walkway at each location. This makes the system both extremely accessible and extremely expensive. The large amount of miscellaneous metal that goes into this design is very expensive and has delayed the project.

Simpler and less expensive approaches would extend the array to the full extent of the available space provided by the structure, simplify the design of the collector support, and eliminate the walkways.



One can see that by changing the level of the structure only slightly, it would be possible to simplify the installation.

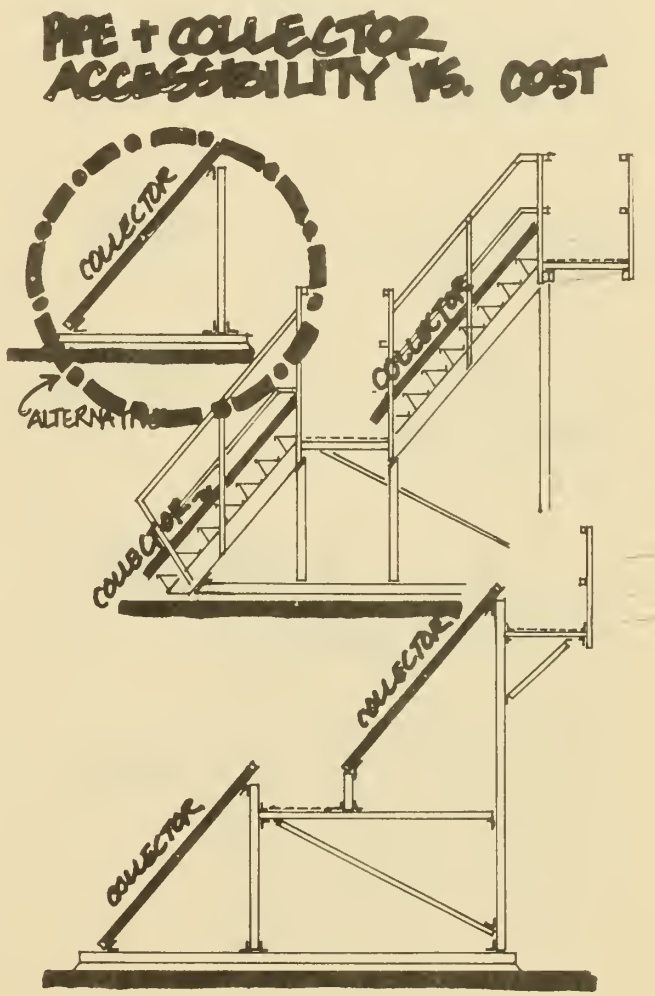


Another approach would be to double up the last two rows of collectors and keep the structure level.

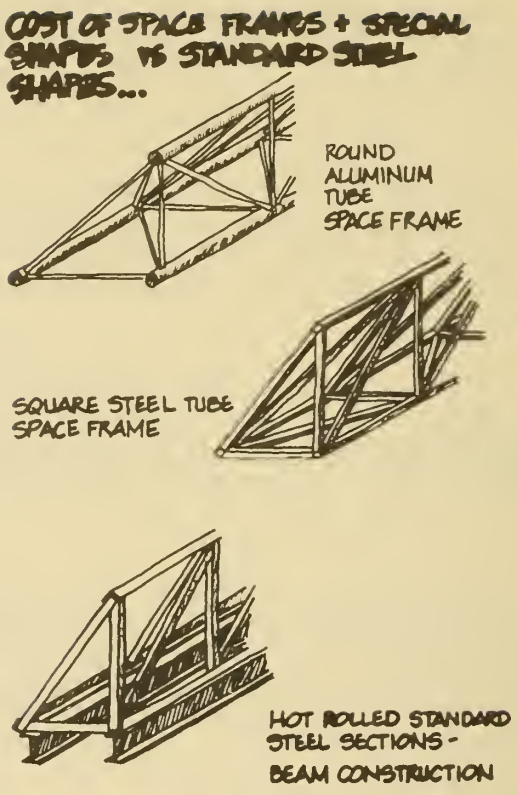
In either case, by keeping the whole structure near the roof, accessibility could have been provided with a ladder rather than with walking surfaces.

I like to call the next design the "O.S.H.A. Special." Notice that ladders have been provided as well as walkways and handrails. Again, this is extremely expensive. In this particular project, which was built by Unistrut, the structure is much too flexible, and the collector will leak if there is any movement in the structure.

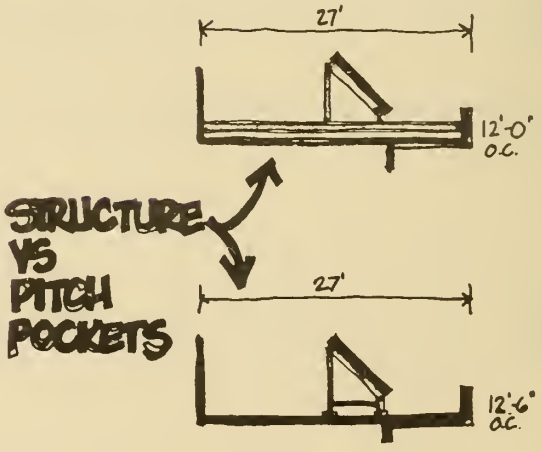
A much less expensive, faster, and easier alternative would have been to place two single rows of collectors (as noted in the circle) on the roof--assuming there is sufficient space available. The simpler structure would be sufficiently rigid, and access would be from the roof.



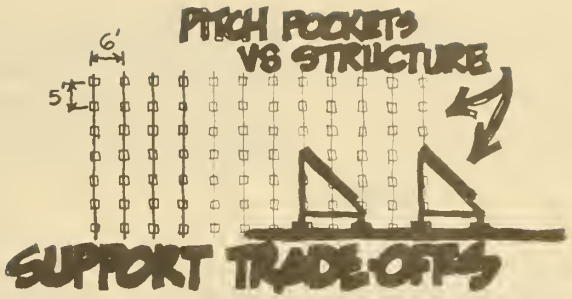
Cost of Space Frames and Special Shapes vs. Standard Steel Shapes--Another cost trade-off involves the design of the collector support. It seems that when the requirements for triangular support and fairly long spans are presented, the first things that come to the designer's mind are special shapes and space frames. In one case, it's an aluminum tube space frame; in another case, it's a square tube steel frame. Both will be handsome structures, if one can afford to build them. However, a much more efficient and less expensive approach is the use of simple, rolled-steel, angle sections with steel beams for the major span.



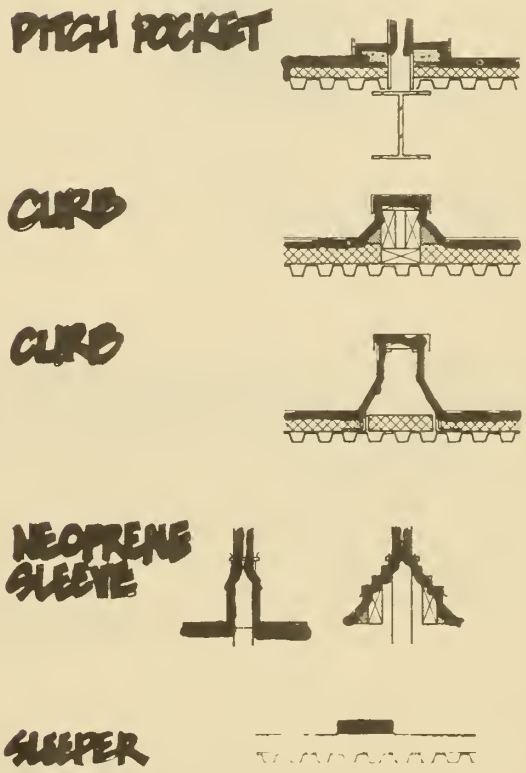
Support Trade-offs--Collector supports ultimately must be tied down to the roof structure. Designers have decided, in some cases to try to avoid penetrating the roofing. In this illustration, you see an attempt to span between a wall and a parapet to avoid penetrating the roofing. After a review, it was discovered that $40,000 could be saved by putting in two pitch pockets 12.5 feet on center, rather than a 27 WF steel beam 12 feet on center.



The structure presented in the adjacent illustration could not take any point loads. As a result, the designers tried to distribute the load over the whole structure by using 700 pitch pockets. The probability that this structure will leak is quite high.



Once you have decided on your basic structural approach, the next question is how to anchor it down. You can use regular pitch pockets, curbs constructed in the field, manufactured curbs or (if your vertical support is a regular shape, such as square or round) a neoprened sleeve. There is also a simple sleeper that can be bolted down.



In some designs there has been an attempt to minimize or eliminate roofing penetrations.

For example, in this case the designer was working with a light frame structure, using sleepers not attached to the roof structure and guy wires to anchor everything in place.

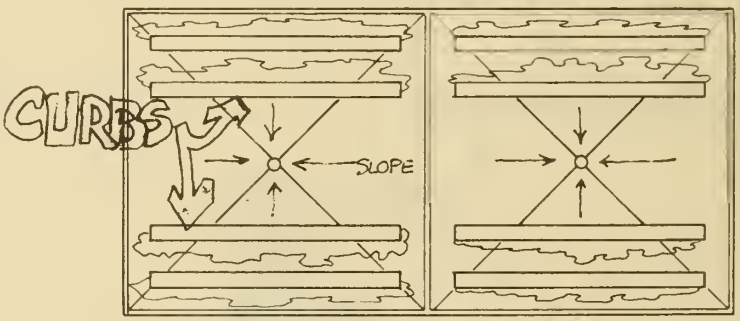
In the adjacent illustration, the structural members span between available vertical supports. Although it was not economical in this case, it can be. If you use this approach, be sure to allow for temperature expansion.

Another interesting approach involved the use of heavy dead-load concrete blocks, tied together with structural members, to withstand the horizontal force of the wind. If your roof can take it, this is a feasible way to go, but you'll pay a penalty in the extra structure required to handle the dead load.

MORE ANCHORAGE DETAILS

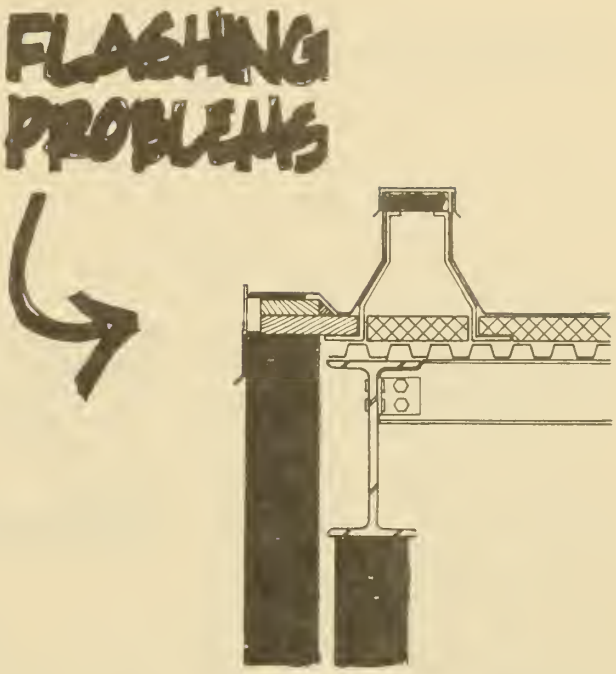
Flashing and Drainage Problems--Remember that flat roofs are not flat; they pitch for drainage. If you decide to use sleepers or continuous curbs, there's a good chance that you will be cutting off the roof's natural drainage. Be sure that your roof can take puddling. Some roofing materials can and will deteriorate under puddled water conditions.

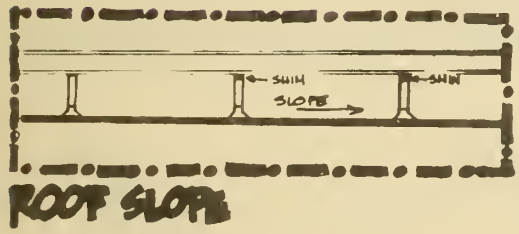
If you are doing a retrofit, check the existing material. In a new installation, be sure that the correct roofing material is specified.



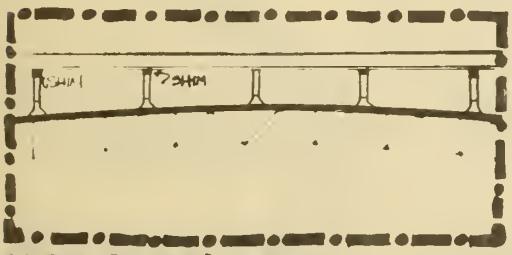
DRAINAGE PROBLEMS

There is a tendency to put supports close to the roof edge to utilize as much surface as possible; this results in interference between the two sets of flashing. Allowances in detailing can correct this problem.





ROOF SLOPE



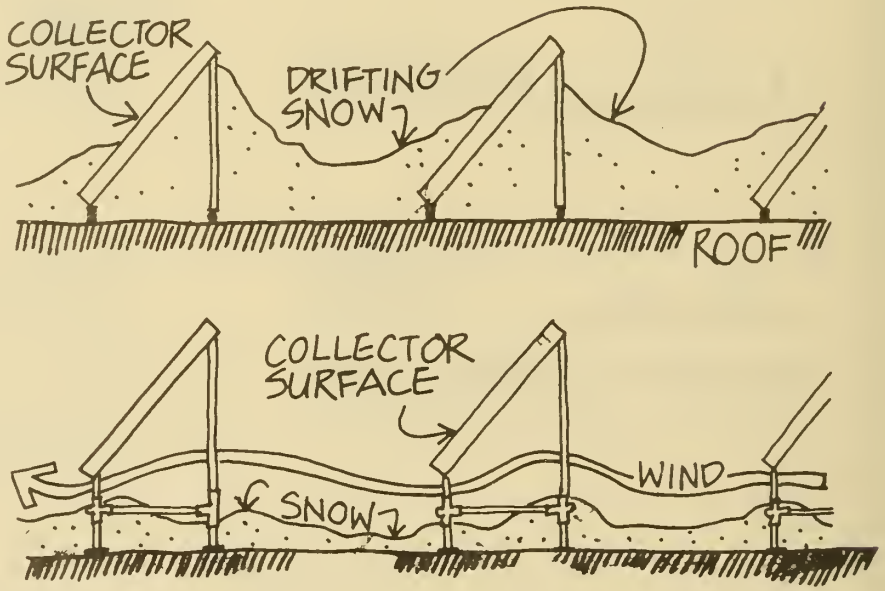
BEAM CAMBER

SHIM DETAILS

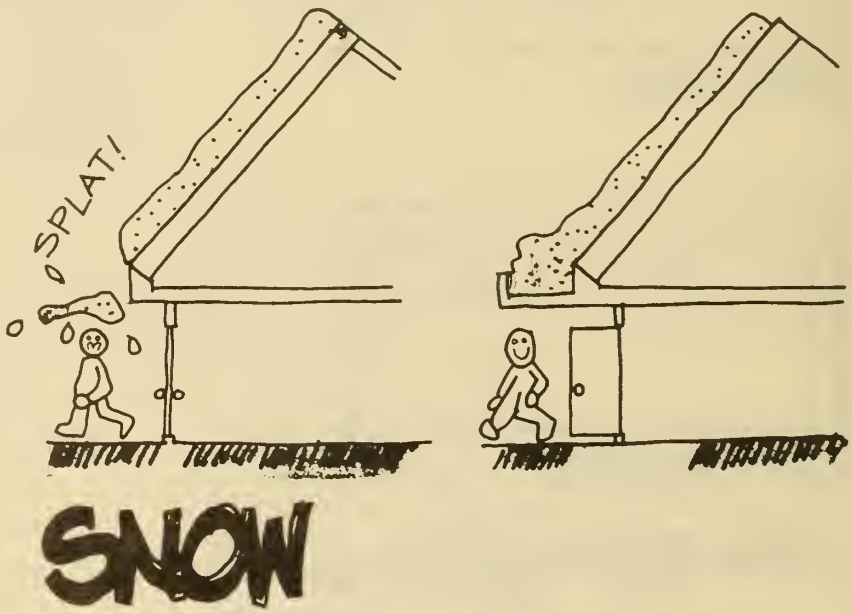
Shim Requirements--I have already noted that flat roofs are not flat. They either pitch to drains or, in long spans, the beams are cambered. Therefore, the design must allow for shimming of the structure. Do not leave it to the contractor. If you do not detail and specify the location and type, you may have serious problems.

Snow Loads, Roof Maintenance, Drain Down--These items may seem unrelated; however, they should all be considered prior to establishing final collector support design.

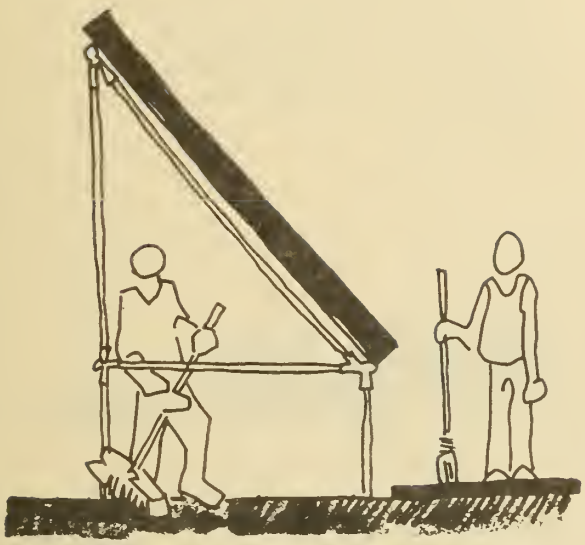
Snow Loads--If collectors are installed close to the roof, they will not only act as a snow fence but will actually cause additional snow accumulation. Besides carrying an extra load, buried collectors obviously are not going to work very well for the first week or two. If you lift them above the roof and let the wind do the shoveling, you can solve a lot of maintenance problems, lower your snow load, and improve the efficiency of your collector.



Also, if your collectors extend over an entry or a walkway, please protect the pedestrians. I think that the pedestrian and your client will appreciate this protection and so will OSHA.



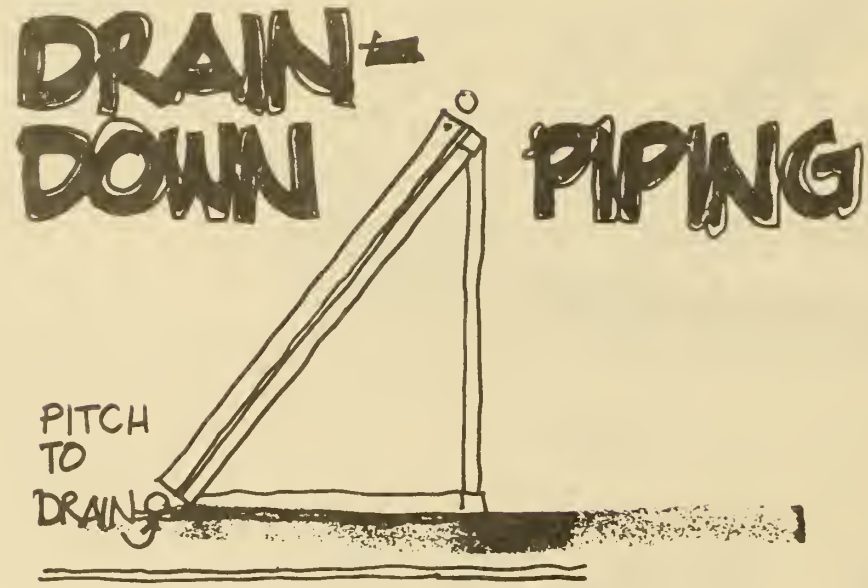
Roof Maintenance--The higher you keep the collectors, including the structure and pipes, the easier it will be to maintain, repair, or even replace the roof in the future. If you provide walking surface accessways for maintenance personnel (with or without ladders), you will find that it will save much wear and tear on the roof. Collectors are often installed at a very shallow angle (especially in the South to best accommodate cooling loads). Limited space creates repair problems. The condition illustrated on the left would be a real "bear" to contend with.

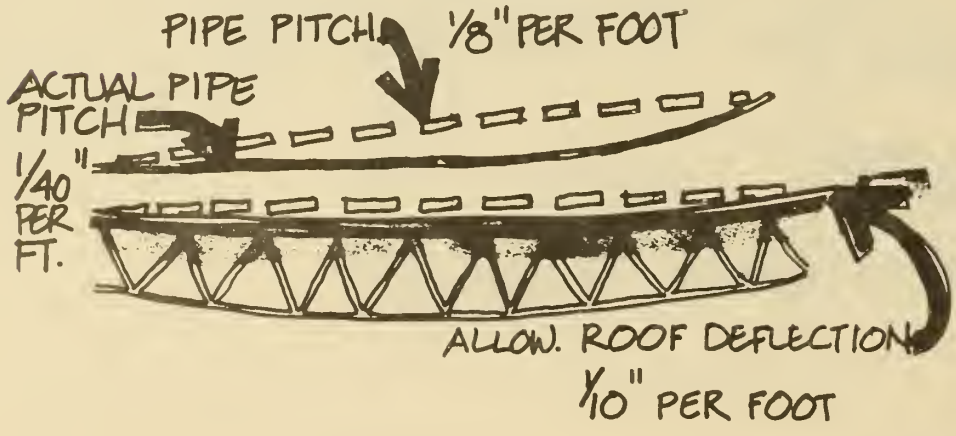


ROOFING PROTECTION

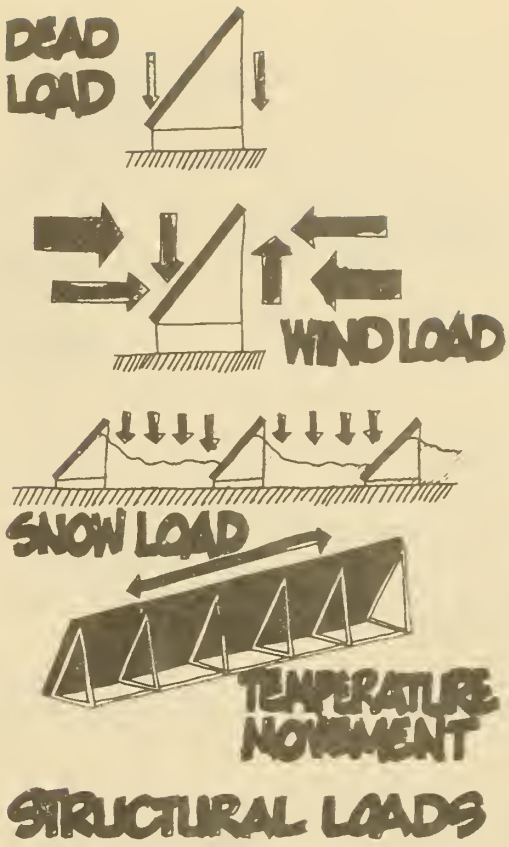
ROOF MAINTENANCE

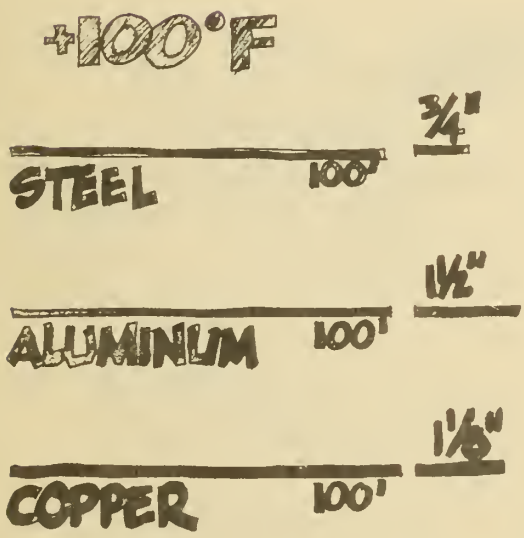
Drain Down--When designing a draindown system, it is very common to draw your collector support and note on the drawings or in the specifications that the pipes must be "pitched to drain." In the case illustrated at right, the designer drew the collector without leaving enough room to install the pipe itself--let alone pitch it to drain. If you want the collectors and piping to pitch to the drain, be sure you detail it so that they can. Either pitch the steel or lift up the collectors so that the pipes can pitch. In addition, most people would like to avoid having pitching pipes all over the place. It does create a vertical problem in installing collectors. Many designers, therefore, are tempted to design the piping with 1/8 inch pitch per foot. The allowable roof deflection on a normal beam is 1/10 inch per foot; therefore, the pipe pitching at certain parts of that span will be 1/40 inch. Normally, we call this a frozen pipe.





Structural Loads--The loads that are imposed by solar installations are fairly well known. There is the dead load, the wind load (with its horizontal and vertical components), and the snow load. These loads can vary depending upon your design. Because of the extent of exterior construction, we have a new load--temperature expansion and contraction due to temperature differential.



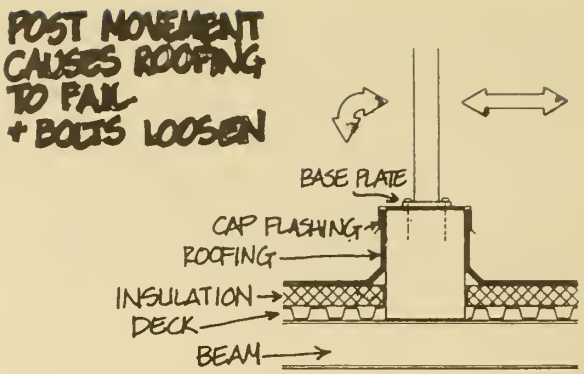


EXPANSION

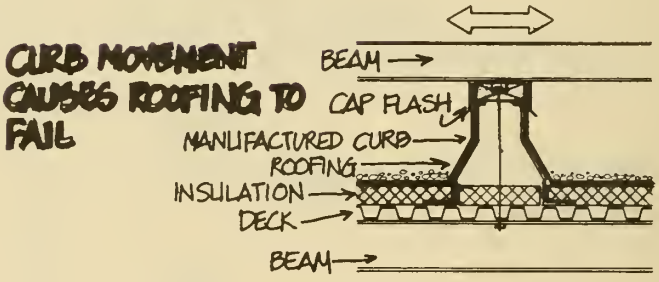
The structure could experience a differential temperature of 160° F between the summer sun and the cold of a winter night, and your piping could experience a 200° F differential. We must, therefore, address the considerable problem of thermal expansion and contraction.

We have found few problems involving the actual structural support of the collector loads; however, the architectural implications of these loads sometimes go unnoticed.

For example, if you fasten a post and base plate to a wood curb, you will have problems if you have only metal fasteners holding the metal base plate through metal flashings. Metal to metal to metal will undoubtedly allow water to enter through the holes caused by the fasteners. In addition to the water problem, the back and forth motion caused by wind forces and temperature differentials actually can cause these fasteners to pull out slightly. If your wood is not treated, it can deteriorate and cause futher problems. Also, as this post rocks, the base plate will tend to cause metal fatigue to the cap flashing at its edges.

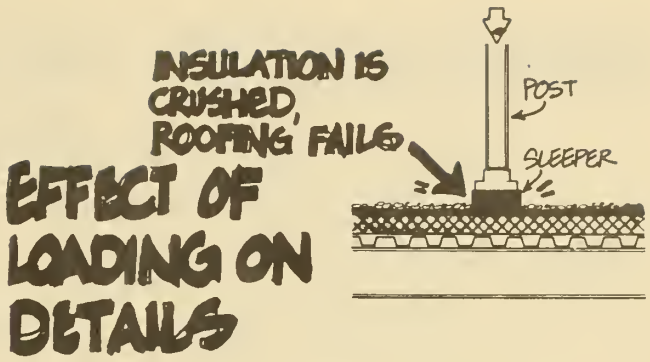


In the next case, the design called for a prefabricated curb bolted to the structure with a beam over it. When the beam moves back and forth, either because of wind load, expansion and contraction, or both, there will tend to be movement of the curb where it joins the roofing that could cause a roofing failure.



An easy way to avoid this problem is to be sure you specify that the edges of the curb be secured to the roof structure. Also, when detailing wood curbs for construction in the field, be sure that you provide sufficient lateral strength.

A very common problem is the use of sleepers on a retrofit so as not to disturb the existing roofing--the sleeper is merely bolted down on top of the roofing. If you put a load onto a sleeper, over normal insulation, the normal insulation will not be able to take the compressive loads that can be applied. The sleeper will compress the insulation and actually shear the waterproofing membrane along the edge of the sleeper, thereby causing leaks.



We can see that there is more than one way to cause a leak. If there is one thing we would prefer to avoid, it is having solar buildings become synonymous with leaking buildings.

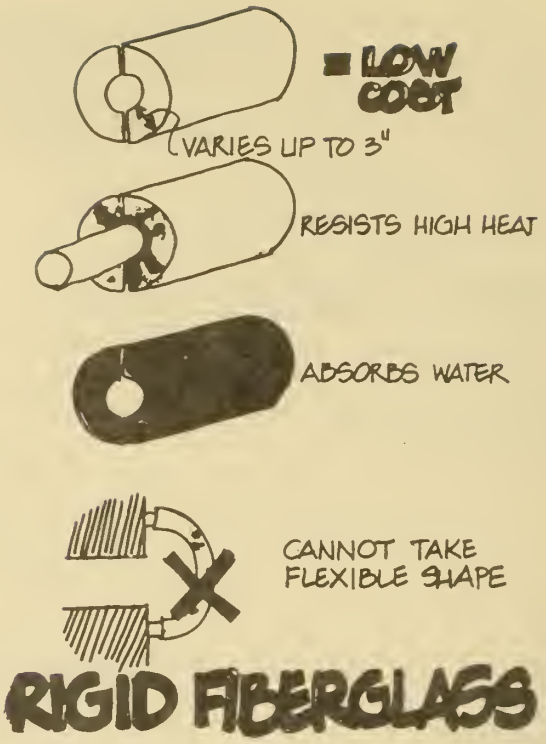
KNOW YOUR COLLECTOR

1. ITS SPECIAL REQUIREMENTS

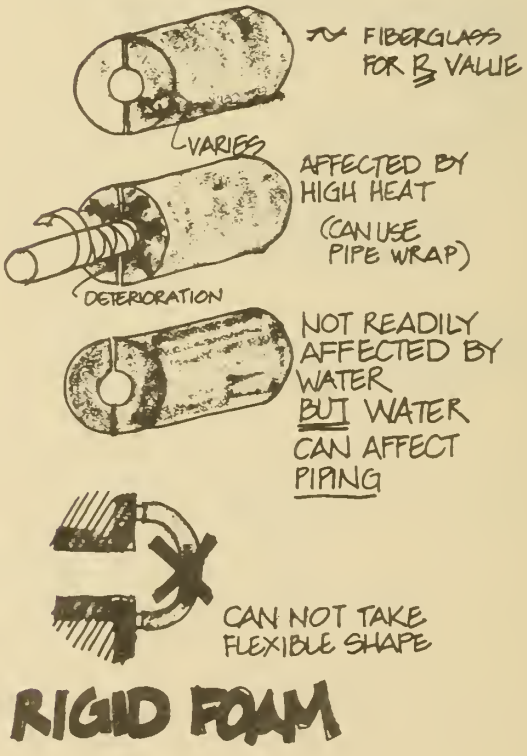
2. ITS SPECIAL CAPABILITIES

Before making the final selection of a collector, be sure that you understand all the attributes of your collector. In addition to such mundane characteristics as collector efficiency and stagnation temperatures, you must consider other truly important characteristics, e.g., attachment requirements and rigidity of structure.

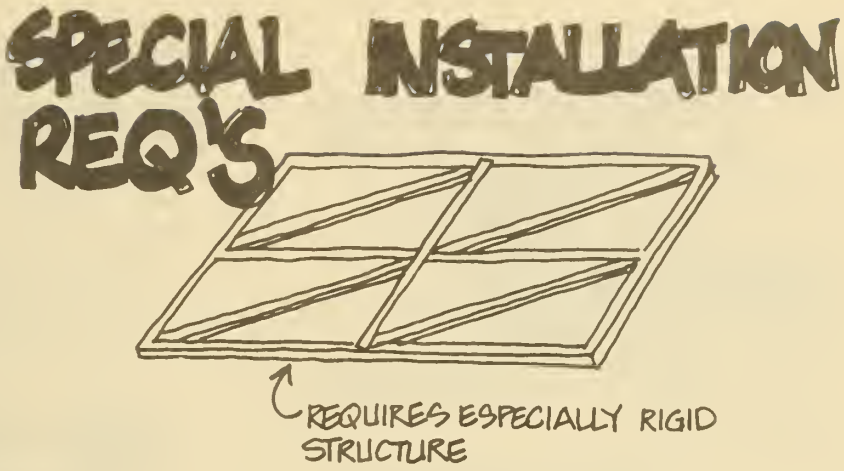
Insulation--Rigid fiberglass is a very common insulating material. It is relatively low in cost, is available in sizes that vary up to 3 inches, and it resists high heat. It absorbs water, however, and if water does get in, you will have a radiator--not an insulator. Also, it cannot take the flexible shape very often required in solar installations.



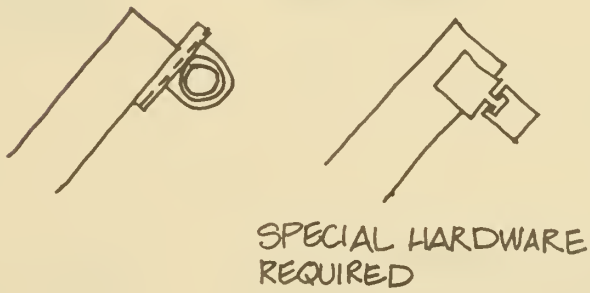
Rigid foam is comparable in cost to fiberglass for the same R value. Similar to glass, it too varies up to about 3 inches. However, it deteriorates very badly if exposed to high heat associated with stagnation. If that is a problem, you might consider some sort of pipe wrap as an inner protection. Pipe wrap is not readily affected by water, but it is not waterproof--you cannot use it as waterproofing. As a matter of fact, water coming in contact with some rigid foams and pipe will cause a mild acid that will deteriorate the pipe. So, it must be waterproofed effectively. Also, rigid foam cannot take the flexible shapes that we encounter with solar.



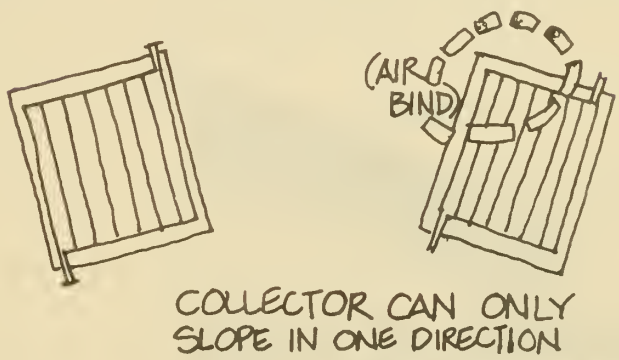
What are the special installation requirements of your collector? One problem, mentioned earlier, is that any movement in the structure (which must be rigid) will cause the collector to leak.



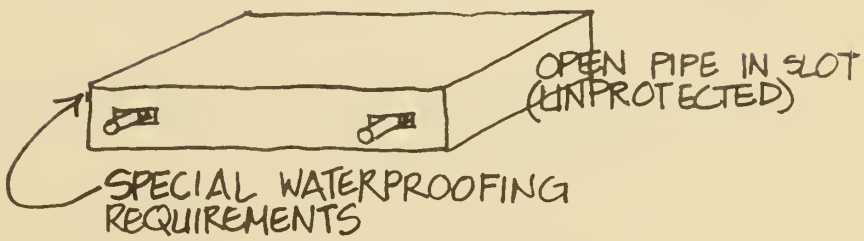
Other collectors require special hardware mounting.



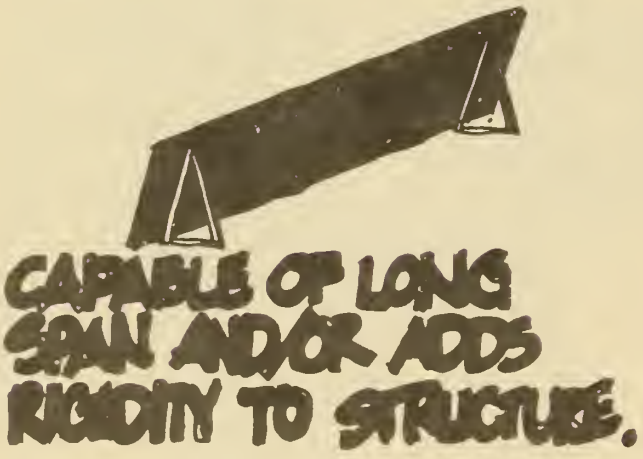
Some collectors can only be tilted in one direction, or they will air bind.



Others have waterproofing problems—especially where the pipes extend out of the collector box.

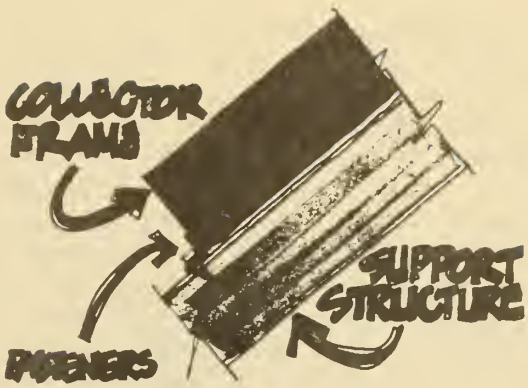


Sometimes collectors have special capabilities. Among these special capabilities is the ability to be fastened in very particular ways, e.g., at the corner. If your collector is capable of spanning and being fastened at dif ferent places, it simplifies your structure. You do not have to have a member in an exact location; you have certain flexibility.



Other collectors are quite long and require very little support because they are sufficiently rigid to take lateral movement. Therefore, put as little structure behind them as possible and use the strength of the collector.

For a successful project, provide for the collectors' requirements and use their capabilities. Whatever your collector problems are, you must know what materials comprise your collector frame, support structure, and fasteners. If there are any differential metals involved, there should be nonmetallic materials separating them to prevent galvanic action.



DIFFERENTIAL METALS

Considering that most cooling equipment requires liquids in the temperature range of 180-200° F, and that most collectors are very hard put to supply that type of energy, any loss due to piping or storage can make the whole system nonoperative.

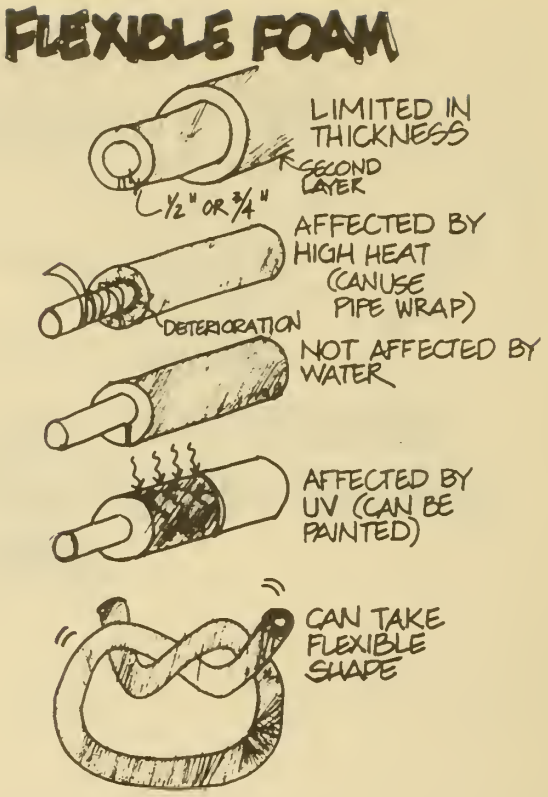
NON-OPTIMUM COLLECTOR TILT OR ORIENTATION OF 10°± WILL AFFECT THE TOTAL SYSTEM PERFORMANCE BY LESS THAN 10%.

HOWEVER,

A POOR PIPING INSTALLATION CAN AFFECT THE TOTAL SYSTEM PERFORMANCE BY MORE THAN 50%.

Insulations--Most insulation materials were not developed for use in solar projects. Although many materials are being adapted and used, they are not suitable in all cases. Let's look at some of the problems.

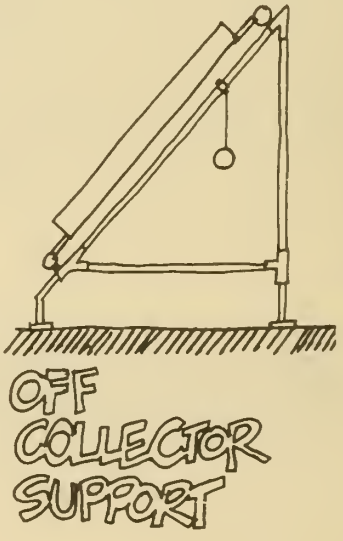
First, flexible foam is only available in 1/2-inch or 3/4-inch thicknesses. To increase your R value you must add a second layer, thereby, doubling your cost. Second, the foam is affected by high heat. (The use of pipe wrap could help in this area.) Third, it is affected by the sun's ultra-violet rays. (It can be painted to protect against ultraviolet deterioration. If you do not paint it, it may deteriorate badly in six months and possibly fail completely within a year.) On the plus side, flexible foam is waterproof and is capable of taking any shape you wish.



Pipe Supports--It is very important to decide how to support your pipes within a solar collector array.

Pipes can be supported off the collector. This is normally done by using soldered copper nipples. Be very careful that the mechanic does not burn out the waterproof seals of the collector. This is a constant problem because the required solder is of a particularly high temperature.

Pipes can also be supported off the collector support. Be sure you have designed space on the collector support to support the piping. You might consider the alternative of supporting the pipes off the back of the support.

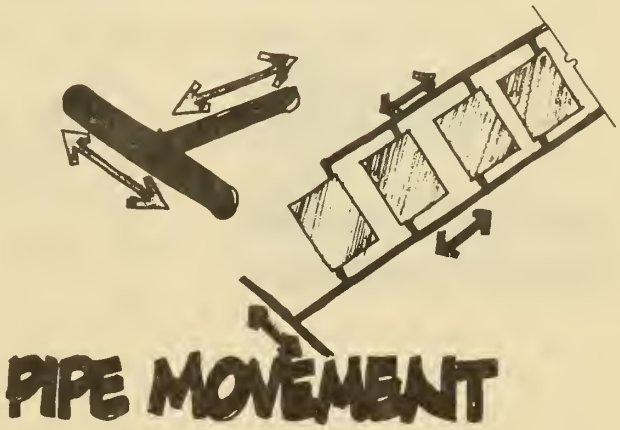


The pipes can also be supported on the roof surface, but try to design the pipes so that the workmen do not use them as a platform.

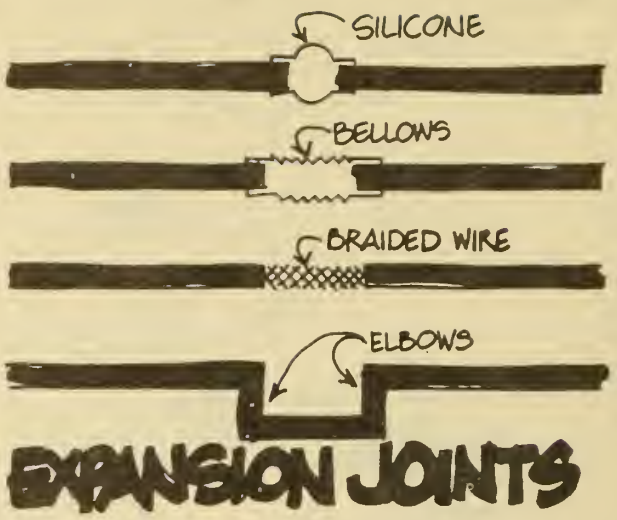
A fairly common way to support pipes is off other pipes, especially in reverse-return designs. In this case, be sure that the pipes are well supported, one from the other, and that they are both free to move.

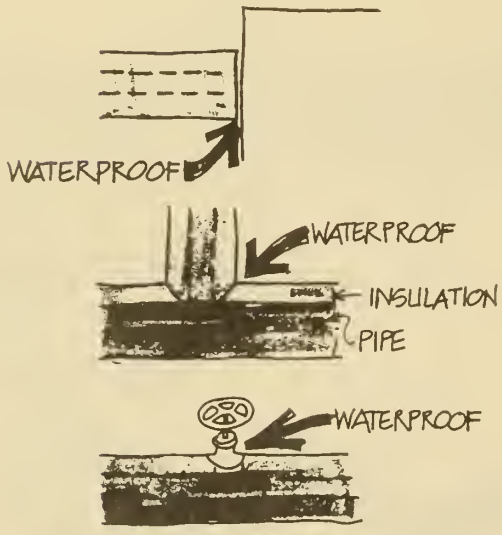
Another common pipe detailing problem is that when pipes are shown as lines on paper, nobody worries about the fact that they cross. Remember that pipes have thicknesses, usually 3 inches or more, and you must account for this thickness in your design. Also, be sure that you design enough space between collectors to allow for the installation of valves or expansion compensators if needed.

Pipe Movement--We have shown that there could be as much as 2 to 2 1/2 inches of movement in the pipe, and it is certain that they are always in opposite directions or at right angles. So, always allow for this pipe movement at change of direction or in extremely long lengths.



Some of the means of compensating for these movements include silicone bulbs, bellows, braided wire or elbow configurations to the piping. Whatever method you choose, design it and show it.





Waterproofing--Frequently, waterproofing problem areas occur between collectors and piping at joints between pipes, change of direction in pipes or pipe T's, or where valves or monitoring equipment protrude through the waterproofing. Be sure that your design answers these problems. This is especially important with fiberglass because any water getting into it will lower the efficiency of the whole system significantly.

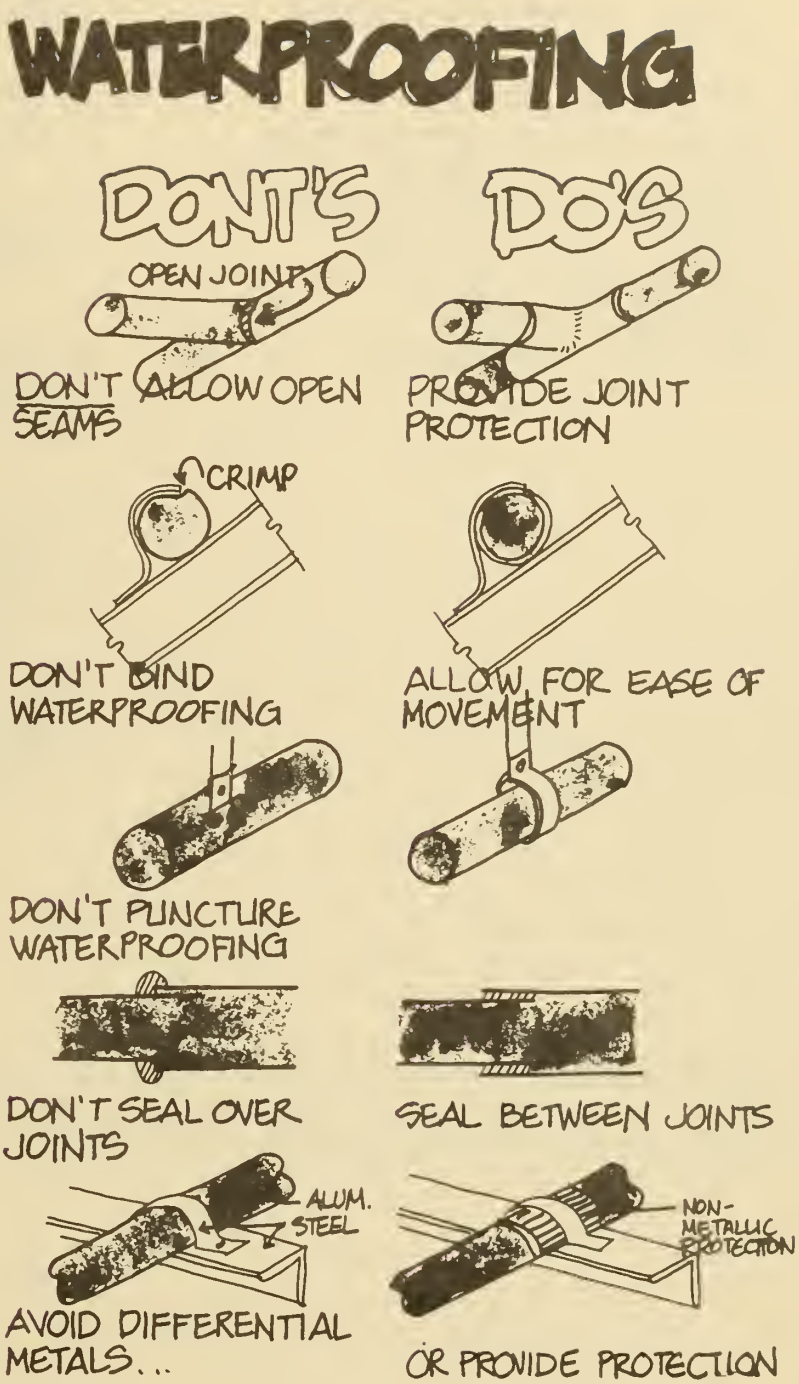
Do not allow open seams. Provide joint protection at all elbows and tees.

Do not bind your pipes when supporting them. Be sure that the pipes are free to move, or, with pipe movement, you will tear either your waterproofing or your insulation.

Do not support piping by puncturing your waterproofing, especially in terms of supporting the pipe directly. Puncturing not only destroys the waterproofing and wreaks havoc with the insulation but also allows a heat bridge to radiate additional energy. Support the pipe loosely on the outside of the waterproofing.

Do not seal the ends of sheet waterproofings. Seal between the seams or the sealant will fail with movement. End seals will fail; seam seals tend not to fail.

Lastly, avoid differential metals if you are using aluminum waterproofing. Be sure that you have nonmetallic protection to prevent galvanic action if you have steel structure or steel clamps. We saw one very attractive installation that had aluminum waterproofing and a sheet of galvanized steel under it with no separation protection. That waterproofing will fail.



CONCLUSION:

COST CONSIDERATIONS

FOR SOLAR PROJECTS TO BE COST-EFFECTIVE THE ARCHITECT/ENGINEER MUST ISOLATE THE DIFFERENT COST TRADE-OFFS AND CHOOSE THE MOST EFFECTIVE APPROACH.

CONSTRUCTION CONSIDERATIONS

- THE A/E MUST ISOLATE ALL CONSTRUCTION PROBLEMS.
- THE A/E MUST ALSO SOLVE EACH PROBLEM.
- DETAILS AND SPECIFICATIONS MUST ADDRESS EACH PROBLEM.
- THE A/E MUST FOLLOW UP WITH SUFFICIENT FIELD VISITS.
- DON'T LEAVE PROBLEMS FOR THE CONTRACTORS TO SOLVE.

We have seen that there is a lot more to designing an effective solar-assisted mechanical system than just choosing your collector area and mechanical equipment; a successful project demands a high level of attention to all details.